

Article

Estimating the Thermal Properties of the Cover and the Floor in a Plastic Greenhouse

Hyung-Kweon Kim ¹, Young-Sun Ryou ¹, Young-Hwa Kim ¹, Tae-Seok Lee ¹, Sung-Sik Oh ¹
and Yong-Hyeon Kim ^{2,*}

¹ Department of Agricultural Engineering, National Institute of Agricultural Sciences, RDA, Jeonju 54875, Korea; khgweon@korea.kr (H.-K.K.); ysryou@korea.kr (Y.-S.R.); kkatte@korea.kr (Y.-H.K.); taeseok84@korea.kr (T.-S.L.); oh9708@korea.kr (S.-S.O.)

² Department of Bio-Industrial Machinery Engineering, Jeonbuk National University, Jeonju 54896, Korea

* Correspondence: yhkim@jbnu.ac.kr

Abstract: This study comprehensively analyzed the heat loss and total heat transfer coefficient (U-value) of a single-span experimental plastic greenhouse covered with a double layer of 0.1 mm thick polyethylene. The air temperature and heat flux (W m^{-2}) of the greenhouse components were measured from 18:00 to 06:00, and the energy balance equations under steady-state conditions were determined. The heat flux and U-value of the roof, sides, front and rear, and floor of the greenhouse were determined and compared. The results showed that these values for the roof play an important role in determining the heat load in the greenhouse, and that the average heat transfer through the floor is very small. The average U-value of the greenhouse cover is a comprehensive value which takes the U-values of the roof, sides, and front and rear into account through the use of an area-weighted average method. Finally, an average U-value of $3.69 \text{ W m}^{-2} \text{ }^{\circ}\text{C}^{-1}$ was obtained through the analysis of the variations in the U-value, as it is related to the difference in air temperature between the interior and exterior of the greenhouse, as well as to the outdoor wind speed. The relationships between the average U-value and those of the roof, sides, and front and rear of the experimental greenhouse were modeled, and were shown to have a highly linear relationship.

Keywords: total heat transfer coefficient; plastic greenhouse; heat flux; area-weighted average; heat load



Citation: Kim, H.-K.; Ryou, Y.-S.; Kim, Y.-H.; Lee, T.-S.; Oh, S.-S.; Kim, Y.-H. Estimating the Thermal Properties of the Cover and the Floor in a Plastic Greenhouse. *Energies* **2021**, *14*, 1970. <https://doi.org/10.3390/en14071970>

Academic Editor: Bashir A. Arima

Received: 12 March 2021

Accepted: 31 March 2021

Published: 2 April 2021

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.



Copyright: © 2021 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

The worldwide use of plastic greenhouses has increased over the last 30 years [1]. In South Korea, they occupied 51,719 ha in 2019, and accounted for approximately 99% of all greenhouses—including plastic, polycarbonate, and glass—used for growing vegetables [2]. The main goal of using plastic greenhouses is to grow vegetables reliably despite harsh external weather conditions. However, the structures of these greenhouses are very weak, and cannot maintain their heat at an appropriate temperature to allow the growth of crops in winter [3]. Bouadila et al. [4] reported that internal climate control is one of the major problems with greenhouses, and the lack of adequate heating has an unfavorable effect on greenhouse crop yield. Nayak and Tiwari [5] found that heating greenhouses is one of the most energy-consuming operations among those performed for protected cultivation. As a result, heating systems are essential equipment in greenhouses, and the cost of heating greenhouses during harsh winters has been a burden on cultivators using greenhouse farming techniques [4,6,7]. Moreover, most of the farmers practicing protected cultivation in South Korea utilize fossil fuels to heat greenhouses—they account for 30–40% of the total operational costs of structures used in protected cultivation [8,9]—with the result that the fluctuations in the international price of oil have increased the management risk of protected horticulture.

In order to save energy in heated greenhouses, farmers have been forced to use advanced thermal insulation materials, such as greenhouse covers, to increase the resistance to weather and minimize greenhouse damage [7,10–13]. Kim et al. [10] reported that the energy-saving effect of greenhouses is mainly represented by a decrease in the total heat transfer coefficient (U-value); the energy consumed by a plastic greenhouse decreased by 70.8 kWh when its U-value decreased by $1 \text{ W m}^{-2} \text{ }^{\circ}\text{C}^{-1}$. Therefore, an accurate calculation of the heat load and thermal insulation of greenhouse covers is required, and these are usually quantified as U-values. It is vitally important to determine greenhouse U-values and analyze them comprehensively because they could be one criterion with which to produce greenhouse covering materials that can improve the thermal insulation and resistance to weather of greenhouses [7,14–16]. Over the past few years, there have been several fragmented studies on the U-values and heat load of plastic greenhouses in South Korea. However, few studies have comprehensively analyzed the heat loss and U-value of a single-span greenhouse covered with the double-layered polyethylene material widely used across South Korea [2,10].

In order to characterize the heat loss from greenhouses, we investigated the variations in heat flux and heat transfer from experimental greenhouse covers and floors. Here, we present the representative U-value for the greenhouse that we calculated using an area-weighted average, the analysis of the variations in the U-value in relation to differences in air temperature and outdoor wind speed, and a comparison of the U-values of the roof, sides, and front and rear of the greenhouse. We also present the relationships between the average U-value and those modelled for the roof, sides, and front and rear of the experimental greenhouse.

2. Materials and Methods

2.1. Experimental Greenhouse and Measurements

The experimental greenhouse was a single-span plastic building oriented to the north and south. Figure 1 shows a schematic of the experimental greenhouse, which had an inner usable floor area for cultivating plants measuring 225 m^2 ($7.5 \text{ m} \times 30 \text{ m}$), and a floor area exposed to the outside air covering 272 m^2 ($8.0 \text{ m} \times 34 \text{ m}$). The central height of the outer cover was 3.3 m. The outer cover area was 454 m^2 , and the surface areas of the roof, sides, and front and rear covers of the greenhouse were 302 m^2 , 108 m^2 , and 44 m^2 , respectively. It was covered with a double layer of 0.1 mm polyethylene films, with the distance between the film layers being 25 cm. It was installed at the Protected Horticulture Research Institute ($35^{\circ}23' \text{ N}$, $128^{\circ}42' \text{ E}$), South Korea, and contained strawberries planted in elevated soil beds.

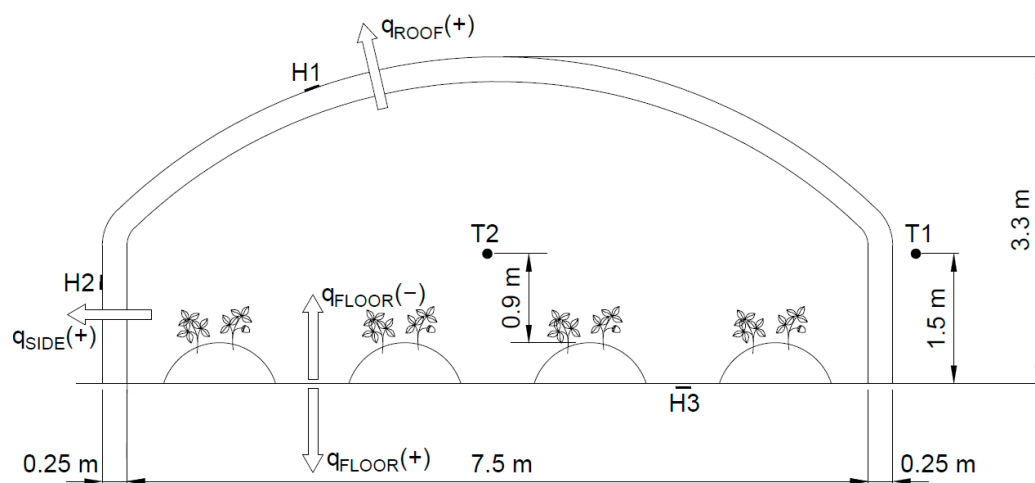


Figure 1. Schematic of the experimental greenhouse: (T1) outdoor air temperature; (T2) indoor air temperature; (H1, H2, H3) heat flow sensors installed on the roof, sides, and floor, respectively.

The greenhouse was heated using a kerosene hot-water boiler which supplied hot water through pipes installed across the length of both sides of the greenhouse. The hot-water boiler was activated at a thermostat set point of 8 °C, thus maintaining a stable indoor air temperature in the greenhouse despite the error and differences in temperature between the upper and lower set points of the thermostat. Measurements were taken on consecutive days between 24 February and 3 March 2016. They were recorded from 18:00 on one day to 06:00 of the next day, and the data recorded during this period were averaged in order to be presented as a result for one day.

The outdoor air temperature was measured approximately 1.5 m off the ground using two TempRetriever RH data loggers (MadaTech, Warner, NH, USA) with accuracies of ± 0.5 °C over a range of -40 – 80 °C and resolution of 0.1 °C. The indoor air temperatures were measured approximately 0.9 m above the furrows using three TempRetriever RH data loggers. The heat flux of the cover and floor of greenhouse were measured using heat flow sensors (MF-180M, EKO Instruments Co., Tokyo, Japan) and stored in a model MV 2000 (Yokogawa, Japan). The sensitivity of the heat flow sensor was 0.025 mV/W m⁻² within a range of -30 – 120 °C. For the floor, the heat flux at a depth of 0.1 m in the elevated soil beds was measured using three heat flow sensors; for the cover, the heat flux of the roof, sides, and front and rear of the experimental greenhouse was measured using three heat flow sensors (Figure 2). The air temperature and heat fluxes from all of the sensors were used to record 10-min averages. The outdoor wind speed was measured from approximately 4.0 m above the ground using a model 05103 wind sensor (R. M. Young, Traverse, Michigan, USA) with an accuracy of ± 0.3 m s⁻¹ over an operating temperature of -50 – 50 °C, and was recorded in a data logger (CR 1000, Campbell Scientific, Logan, Utah, USA). The wind speed was measured every minute, and was averaged at 10-min intervals.



Figure 2. Photographs of the greenhouse with the heat flow sensors: (a) roof, (b) side, and (c) floor.

2.2. Heat Balance in the Greenhouse

Under steady-state conditions, the energy balance equation of the greenhouse can be expressed as follows [13,17]:

$$Q = q_{floor}A_{floor} + q_{cover}A_{cover} \quad (1)$$

where Q is the average heat transfer to the greenhouse (W), q_{floor} is the heat flow per unit of inner usable area of the greenhouse floor (W m⁻²), A_{floor} is the floor area (m²), q_{cover} is the heat flow per unit area of the greenhouse cover (W m⁻²), and A_{cover} is the cover area (m²). The direction of the heat flow is positive towards the exterior of the greenhouse (going away from the cover and the floor), and negative toward the interior of the greenhouse (coming towards the cover and the floor).

The expression on the right-hand side of Equation (1) sums the exchanges between the greenhouse floor and the surface of the cover. The $q_{cover}A_{cover}$ value was determined using the following equation:

$$q_{cover}A_{cover} = q_{roof}A_{roof} + q_{side}A_{side} + q_{front-rear}A_{front-rear} \quad (2)$$

where q_{roof} , q_{side} , and $q_{front-rear}$ (W m⁻²) are, respectively, the heat fluxes of the roof, sides, and front and rear covers of the greenhouse; A_{roof} , A_{side} , and $A_{front-rear}$ (m²) are the surface

areas of the roof, sides, and front and rear covers of the greenhouse, respectively; and A_{cover} is the sum of the surface area of the roof, sides, and front and rear covers of the greenhouse. It is assumed that the heat flux of the front cover is equal to that of the rear cover.

The heat flux of the roof, sides, and front and rear covers of the greenhouse can be expressed as follows [7,14,18,19]:

$$q_{cover} = U (T_{in} - T_{out}) \quad (3)$$

where U is the U-value ($W m^{-2} ^\circ C^{-1}$) of the greenhouse cover, T_{in} is the indoor air temperature ($^\circ C$), and T_{out} is the outdoor air temperature ($^\circ C$).

The U-value embodies the coefficients of heat transfer by conduction, convection, and radiation [17,20,21]. In Equation (3), the U-value is given as an area-weighted average, as follows [22,23]:

$$U = \frac{q_{cover}}{(T_{in} - T_{out})} = \frac{U_{roof}A_{roof} + U_{side}A_{side} + U_{front-rear}A_{front-rear}}{A_{cover}} \quad (4)$$

where U_{roof} , U_{side} , and $U_{front-rear}$ are the heat transfer coefficients ($W m^{-2} ^\circ C^{-1}$) of the roof, sides, and front and rear covers of the greenhouse, respectively.

3. Results and Discussion

3.1. Climatic Conditions

Figure 3 shows the change in the outdoor and indoor air temperatures, and outdoor wind speed, gathered as 10-min data and averaged to represent one night. The outdoor air temperature was $0.5 ^\circ C$ on average, varying between -3.0 and $7.0 ^\circ C$; the indoor air temperature was $8.5 ^\circ C$ on average, varying between 6.3 and $13.2 ^\circ C$; the outdoor wind speed ranged from 0.5 to $2.3 m s^{-1}$, with an average value of $1.3 m s^{-1}$.

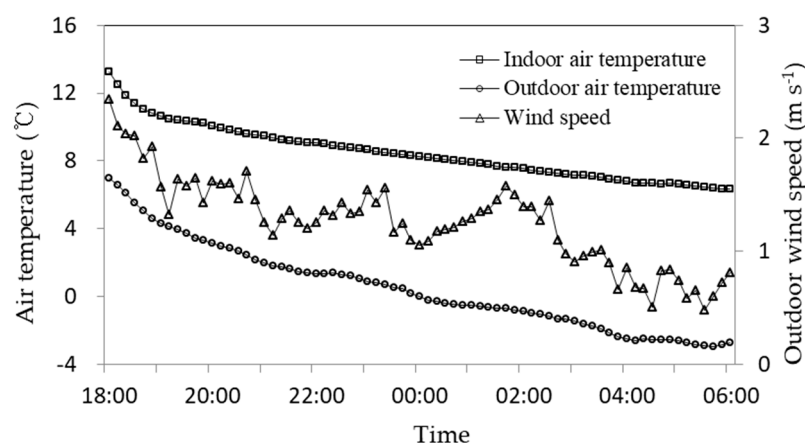


Figure 3. Variation in the outdoor wind speed and air temperature inside and outside the experimental greenhouse (24 February and 3 March 2016).

3.2. Heat Flux and Heat Transfer from the Cover and the Floor

Figure 4 shows the hourly variations in the heat flux through the greenhouse cover and floor. The heat flux of the roof, sides, and front and rear range, respectively, from 26.6 to $38.0 W m^{-2}$, at an average of $34.3 W m^{-2}$; from 13.8 to $21.4 W m^{-2}$, at an average of $19.1 W m^{-2}$; and from 15.2 to $21.5 W m^{-2}$, at an average of $18.6 W m^{-2}$. The heat flux values of the sides and front and rear of greenhouse are similar; they are equivalent to 55.7% and 54.0% , respectively, of the heat flux of the roof.

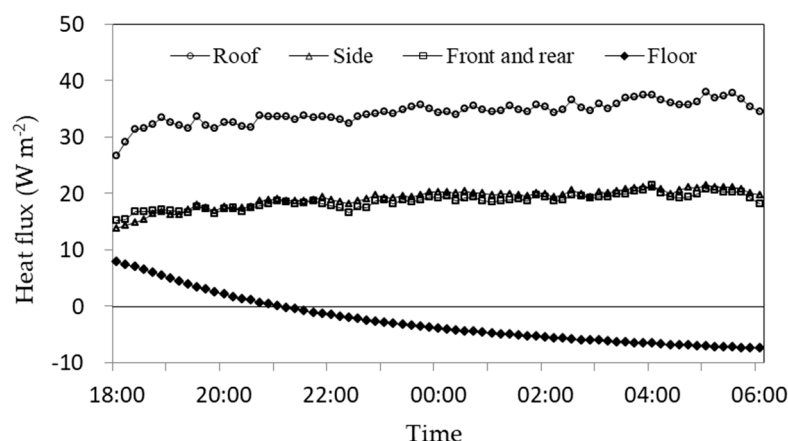


Figure 4. Variations in the heat fluxes of the cover (roof, sides, front and rear) and floor of the experimental greenhouse (24 February and 3 March 2016).

These results show that the heat flux of the greenhouse roof has an important effect on the heat load due to the transfer of the inside-greenhouse heat driven by the buoyancy of the air. This reveals that designing greenhouse structures to minimize the roof area available and to insulate carefully the roof area could play a major role in saving the heat energy therein. This result is in close agreement with those in previous studies [3,13].

Figure 4 also shows that the heat flux through the floor decreases from 7.9 to -7.5 W m^{-2} , at an average of -2.6 W m^{-2} , as a function of time. This confirmed that the average contribution of heat from the floor represented approximately 7.6% of the heat flux of greenhouse roof. The heat flux through the floor reached 0 at 21:00. From 18:00 to 21:00, the heat flux through the floor moved downwards, thus contributing negatively to the greenhouse heating load, whereas the heat flux through the floor after 21:00 moved upwards, thus contributing positively to the load after that time. This is because the floor plays an important role in heat storage and release; various factors have been known to influence the direction (negative, positive) of the heat fluxes of the cover and the floor of the greenhouse: the solar radiation captured by the greenhouse floor during the day, the internal temperature setting of the greenhouse, and the difference in the internal and external temperatures [3,14]. From 18:00 to 21:00, the floor stores heat from the air in the greenhouse and canopy (taken up by them in the form of solar radiation during the day), whereas from 21:00 to 06:00, the floor releases heat into the greenhouse when the difference between the indoor and outdoor temperature exceeds approximately 7.5 $^{\circ}\text{C}$ at 21:00 (Figure 3).

Figure 5 shows the heat transfer rate through the cover and floor of the greenhouse, as determined by multiplying the heat flux and the area of the two components (as described in Equations (1) and (2)).

Figure 5 also shows that the heat transfer rate through the floor decreases from 1.8 to -1.7 kW , at an average of -0.6 kW , as a function of time. The average heat transfer through the floor represented about 4.4% of the heat lost from the greenhouse through the cover. The low transfer rate of heat from the floor here is similar to the results from previous studies [7,13,14]. This suggests that the heat transfer from the floor was assumed to be relatively low, and can thus be ignored in terms of the total heat transferred from the greenhouse [7].

The area of the greenhouse components and the average heat transfer from them are listed in Table 1. The rate at which heat was transferred through the cover was determined as the sum of the heat transfer from the roof, sides, and front and rear; it varied between 10.2 kW and 14.7 kW (average of 13.3 kW). The rate of the heat transfer through the roof, sides, and front and rear ranged, respectively, from 8.0 kW to 11.5 kW , from 1.5 kW to 2.3 kW , and from 0.7 kW to 1.0 kW . The rates of the heating load from the greenhouse cover were calculated to be 78.2%, 15.8%, and 6.0% through the roof, sides, and front and rear,

respectively. As before, the component of the greenhouse that bore most of the heat load was the roof, owing to heat transfer driven by the buoyancy of the air inside the greenhouse and its area.

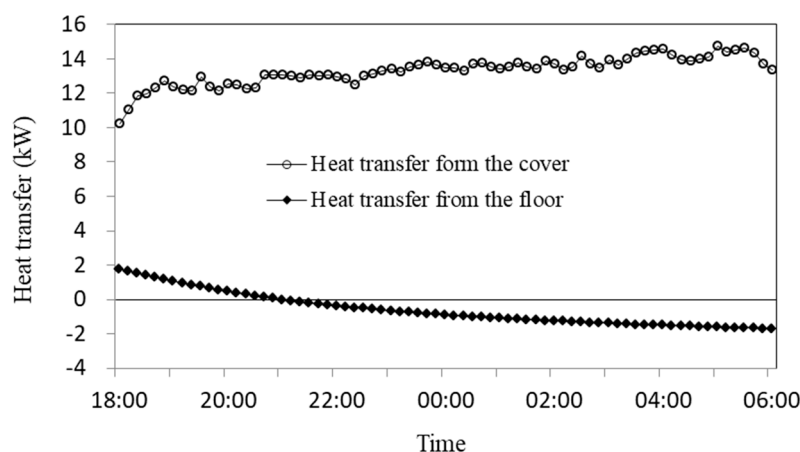


Figure 5. Variations in the heat transfer from the cover (roof, sides, front and rear) and floor of the experimental greenhouse (24 February and 3 March 2016).

Table 1. Area and average heat transfer from the roof, sides, front and rear cover, and floor of the experimental greenhouse.

Greenhouse Component	Area (m ²)	Heat Transfer (kW)
Roof	302	10.4
Sides	108	2.1
Front and rear	44	0.8
Floor	225	−0.6

3.3. Assessing the U-Values of the Greenhouse Cover

Figure 6 shows the hourly variations in the U-values through the greenhouse cover (roof, sides, and front and rear), including the average U-value (Equation (3)). The average U-value of the greenhouse cover is a comprehensive value which was determined as the area-weighted average U-values of the roof, sides, and front and rear thereof, and it was determined using Equation (4).

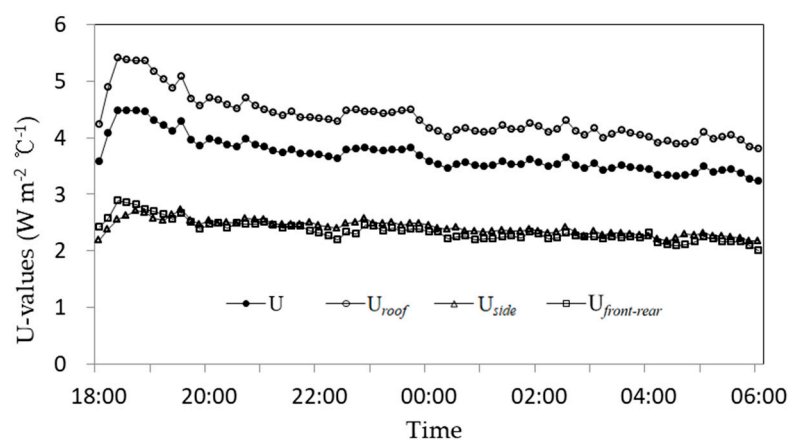


Figure 6. U-values of the components of the experimental greenhouse: its cover (U), roof (U_{roof}), sides (U_{side}), and front and rear U-value ($U_{front-rear}$) (24 February and 3 March 2016).

The average U-values reached a maximum of $4.49 \text{ W m}^{-2} \text{ }^{\circ}\text{C}^{-1}$ at 18:20, whereas the maximum U-values of the roof, sides, and front and rear were $5.42 \text{ W m}^{-2} \text{ }^{\circ}\text{C}^{-1}$ at

18:20, $2.73 \text{ W m}^{-2} \text{ }^{\circ}\text{C}^{-1}$ at 19:30, and $2.88 \text{ W m}^{-2} \text{ }^{\circ}\text{C}^{-1}$ at 18:20, respectively. These results indicated that the greenhouse U-values reached a peak just after sundown, when the outdoor air temperature during the experimental period was relatively high. This finding also agrees with a result indicating that high outdoor air temperatures and a low difference in the indoor and outdoor temperatures produced higher U-values [17,18,24,25]. The mean U-values of the roof, sides, and front and rear of the greenhouse were 4.35, 2.41, and $2.35 \text{ W m}^{-2} \text{ }^{\circ}\text{C}^{-1}$, respectively, whereas the average U-value of the greenhouse cover was $3.69 \text{ W m}^{-2} \text{ }^{\circ}\text{C}^{-1}$. These results are very similar to those in Kim et al. [10] and the Japan Greenhouse Horticulture Association handbook [26], which shows the U-values of a double-layered plastic greenhouse to be $3.85 \text{ W m}^{-2} \text{ }^{\circ}\text{C}^{-1}$ and $3.80 \text{ W m}^{-2} \text{ }^{\circ}\text{C}^{-1}$, respectively.

Figure 7 shows the cover U-value as a function of the difference in temperature, ΔT , between the interior and exterior of the greenhouse. The U-value of the cover decreased as the temperature difference increased. This finding showed the same trend as that reported in previous studies [24,25], particularly when the difference between the interior and exterior temperatures was approximately $5.8 \text{ }^{\circ}\text{C}$ or higher. The equation of the regression model was $U = -0.277\Delta T + 5.902$ (coefficient of determination $R^2 = 0.845$). This equation indicates a decrease of $0.277 \text{ W m}^{-2} \text{ }^{\circ}\text{C}^{-1}$ in the U-value of the cover for every $1 \text{ }^{\circ}\text{C}$ increase in ΔT . This shows that the average U-value has a negative linear relationship with ΔT .

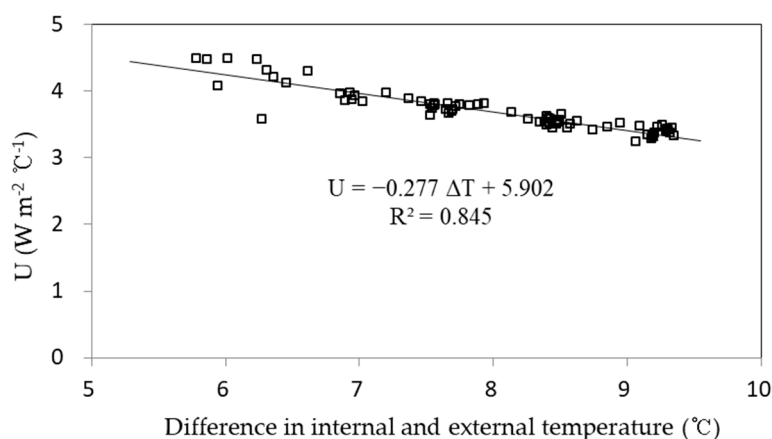


Figure 7. U-value of the cover of the experimental greenhouse (U) as function of ΔT , the temperature difference between the interior and the exterior of the greenhouse (24 February and 3 March 2016).

The relationship between the average U-value and the outdoor wind speed (w) is presented in Figure 8, which shows that the average U-value increases with the increase in outdoor wind speed. This finding agreed with those of many previous studies [18,24,25].

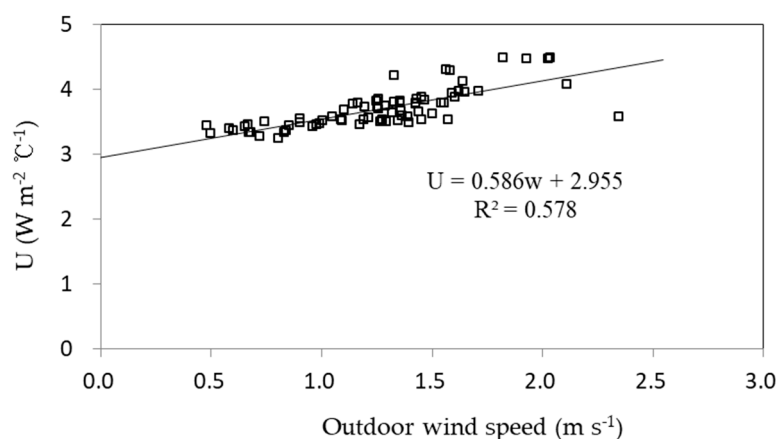


Figure 8. U-value of the cover of the greenhouse (U) as a function of the outdoor wind speed (w). The solid lines represent a linear regression plot (24 February and 3 March 2016).

Figure 8 also shows that the values between the average U-value of the cover and the outdoor wind speed have a positive linear correlation. The equation of the regression model was $U = 0.586w + 2.955$ ($R^2 = 0.578$). This indicates that the average U-value increased by $0.586 \text{ W m}^{-2} \text{ }^\circ\text{C}^{-1}$ when the outdoor wind speed increased by 1 m s^{-1} . Although the R^2 values of the average U-value as a function of ΔT were greater than those of the outdoor wind speed, the results indicated that the principal parameters affecting the U-value of the cover of the greenhouse are ΔT and w .

Figure 9a–c shows that the average U-value for the experimental greenhouse, shown as a function of the U-values of its roof, sides, and front and rear, has a clear linear relationship with the latter U-values, respectively; the equations of the regression models are $U = 0.778U_{\text{rear}} + 0.307$ (Figure 9a), $U = 2.072U_{\text{side}} - 1.303$ (Figure 9b), and $U = 1.608U_{\text{front-rear}} - 0.082$ (Figure 9c). The corresponding R^2 values are 0.997, 0.805, and 0.934. These indicate that the independent variables contributed to the average U-value, and that the reliability of the regression models was extremely high, demonstrably. The average U-value increased as the U-values of the roof, sides, and front and rear increased, as expected; therefore, it was both very appropriate and easy to obtain the average U-value using the U-values of the individual components of the experimental greenhouse.

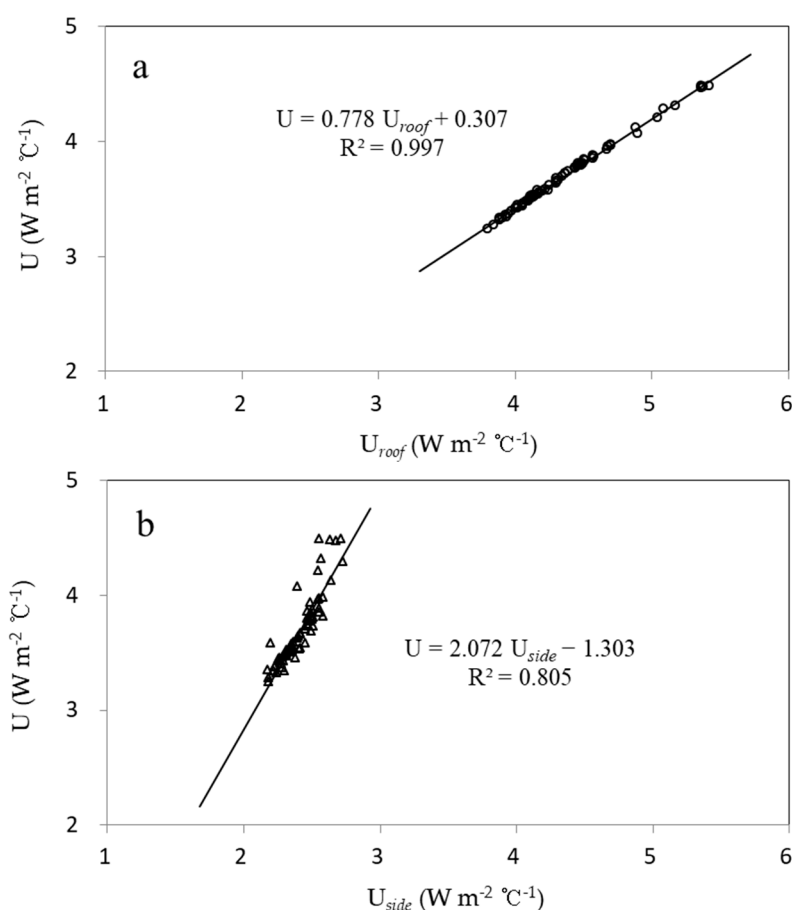


Figure 9. Cont.

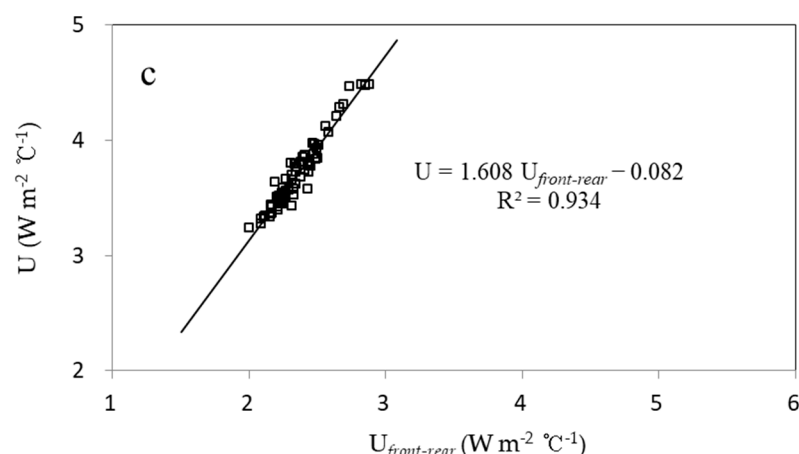


Figure 9. Average U-value (U) of the cover of the experimental greenhouse, as a function of the U-values of the roof (U_{roof}), sides (U_{side}), and front and rear ($U_{front-rear}$); the relationship between (a) U and U_{roof} , (b) U and U_{side} , and (c) U and $U_{front-rear}$ (24 February and 3 March 2016).

4. Conclusions

This study was conducted in order to evaluate the heat loss from and determine the U-value for the components (roof, sides, and front and rear) of a plastic greenhouse, such as those that are common in South Korea. The greenhouse was covered with a double layer of polyethylene of 0.1 mm thickness. The average heat fluxes of the roof, sides, and front and rear of the greenhouse were 34.3 W m^{-2} , 19.1 W m^{-2} , and 18.6 W m^{-2} , respectively. The heat flux through the floor reached 0 at 21:00. From 18:00 to 21:00, the heat flux through the floor contributed negatively to the heat load of the greenhouse, but made a positive contribution after 21:00. Thus, the greenhouse floor can be treated as a thermal storage area which absorbs and radiates heat. The roof is the primary contributor to the heat transfer from the greenhouse cover; its mean heat flux value was 10.4 kW, representing approximately 78.2% of the heat load of the cover. However, the average heat transferred through the floor was -0.6 kW , which represents 4.4% of that of the cover; this is a very low value, and can thus be ignored.

The U-value includes the coefficients of heat transfer via conduction, convection, radiation, and infiltration. The average U-values for the greenhouse, comprehensively reviewed in terms of the U-values of its roof, sides, and front and rear, were calculated based on the area of these components using a weighted average method. The average U-value obtained for the greenhouse with its double-layered cover was $3.69 \text{ W m}^{-2} \text{ °C}^{-1}$. This study further demonstrated that the difference in the air temperature inside and outside the greenhouse and the outdoor wind speed also had an influence on the U-value; when the former and the latter increased by 1 °C and 1 m s^{-1} , respectively, the average U-value decreased by $0.277 \text{ W m}^{-2} \text{ °C}^{-1}$ and increased by $0.586 \text{ W m}^{-2} \text{ °C}^{-1}$, respectively. The relationship between the U-value of the cover and those of the roof, sides, and front and rear of the experimental greenhouse fit a directly proportional regression model, and can thus be computed easily from the U-values of the individual components of the experimental plastic greenhouse.

Author Contributions: Conceptualization, H.-K.K. and Y.-H.K. (Yong-Hyeon Kim); methodology, Y.-S.R.; software, T.-S.L.; validation, Y.-H.K. (Young-Hwa Kim) and S.-S.O.; writing—original draft preparation, H.-K.K.; writing—review and editing, Y.-S.R. and T.-S.L.; visualization, Y.-H.K. (Young-Hwa Kim) and S.-S.O.; supervision, H.-K.K. and Y.-H.K. (Yong-Hyeon Kim): All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: This work was supported by the Cooperative Research Program for Agriculture Science & Technology Development [Project No. PJ01425701], Rural Development Administration, Korea.

Conflicts of Interest: The authors declare no conflict of interest.

References

- Baille, A.; López, J.C.; Bonachela, S.; González-Real, M.M.; Montero, J.I. Night energy balance in a heated low-cost plastic greenhouse. *Agric. Meteorol.* **2006**, *137*, 107–118. [CrossRef]
- Ministry of Agriculture, Food and Rural Affairs (MAFRA). *The Status of Vegetable Greenhouse Facilities and Vegetables Production in 2019*; MAFRA: Sejong, Korea, 2020; Available online: <https://lib.mafra.go.kr/skyblueimage/5752.pdf> (accessed on 12 January 2021).
- Xu, J.; Li, Y.; Wang, R.Z.; Liu, W. Performance investigation of a solar heating system with underground seasonal energy storage for greenhouse application. *Energy* **2014**, *67*, 63–73. [CrossRef]
- Bouadila, S.; Kooli, S.; Skouri, S.; Lazaar, M.; Farhat, A. Improvement of the greenhouse climate using a solar air heater with latent storage energy. *Energy* **2014**, *64*, 663–672. [CrossRef]
- Nayak, S.; Tiwari, G.N. Theoretical performance assessment of an integrated photovoltaic and earth air heat exchanger greenhouse using energy and exergy analysis methods. *Energy Build.* **2009**, *41*, 888–896. [CrossRef]
- Yang, S.H.; Rhee, J.Y. Utilization and performance evaluation of a surplus air heat pump system for greenhouse cooling and heating. *Appl. Energy* **2013**, *105*, 244–251. [CrossRef]
- Teitel, M.; Barak, M.; Antler, A. Effect of cyclic heating and a thermal screen on the nocturnal heat loss and microclimate of a greenhouse. *Biosys. Eng.* **2009**, *102*, 162–170. [CrossRef]
- Rural Development Administration (RDA). *Energy Saving Technology for Protected Horticulture (Guide for Agricultural Techniques)*; RDA: Jeonju, Korea, 2014.
- Rural Development Administration (RDA). *Guidebook of Energy Saving for Overcoming High. Oil Price in Protected Horticulture*; RDA: Suwon, Korea, 2008.
- Kim, H.K.; Kang, G.C.; Moon, J.P.; Lee, T.S.; Oh, S.S. Estimation of thermal performance and heat loss in plastic greenhouses with and without thermal curtains. *Energies* **2018**, *11*, 578. [CrossRef]
- Kim, H.K.; Kim, Y.S.; Jeon, J.G.; Paek, Y.; Lee, J.H.; Khoshimkhujiev, B.; Kim, Y.C. Evaluation of optimal water flow and temperature in response to outdoor air temperature in plastic greenhouse with recirculated water curtain system. *J. Mech. Sci. Technol.* **2017**, *31*, 3043–3051. [CrossRef]
- Ghosal, M.K.; Tiwari, G.N. Mathematical modeling for greenhouse heating by using thermal curtain and geothermal energy. *Sol. Energy* **2004**, *76*, 603–613. [CrossRef]
- Arinze, E.A.; Schoenau, G.J.; Besant, R.W. Experimental and computer performance evaluation of a movable thermal insulation for energy conservation in greenhouses. *J. Agric. Eng. Res.* **1986**, *34*, 97–113. [CrossRef]
- Shin, H.H.; Nam, S.W. Validation of load calculation method for greenhouse heating design and analysis of the influence of infiltration loss and ground heat exchange. *Kor. J. Hort. Sci. Technol.* **2015**, *33*, 647–657.
- Fokaides, P.A.; Kalogirou, S.A. Application of infrared thermography for the determination of the overall heat transfer coefficient (U-Value) in building envelopes. *Appl. Energy* **2011**, *88*, 4358–4365. [CrossRef]
- Suleiman, B.M. Estimation of U-value of traditional North African houses. *Appl. Eng.* **2011**, *31*, 1923–1928. [CrossRef]
- Perdigones, A.; García, J.L.; Pastor, M.; Benavente, R.M.; Luna, L.; Chaya, C.; de la Plaza, S. Effect of heating control strategies on greenhouse energy efficiency: Experimental results and modeling. *Trans. Asabe* **2006**, *49*, 143–155. [CrossRef]
- Ozturk, H.H. Experimental determination of the overall heat loss coefficient for energy requirement of greenhouse heating. *Int J. Energy Res.* **2005**, *29*, 937–944. [CrossRef]
- Papadakis, G.; Briassoulis, D.; Scarascia Mungnozza, G.; Vox, G.; Feuilloley, P.; Stoffers, J.A. Review Paper (SE—Structures and Environment): Radiometric and thermal properties of, and testing methods for, greenhouse covering materials. *J. Agric. Eng. Res.* **2000**, *77*, 7–38. [CrossRef]
- American Society of Agricultural Engineers (ASAE). ASAE Standards 2003: ANSI/ASAE EP406.4 JAN03 Heating, Ventilating and Cooling Greenhouses. Available online: http://ceac.arizona.edu/sites/default/files/asae_-_heating_ventilating_and_cooling_greenhouses.pdf (accessed on 7 May 2020).
- Mills, A.F. *Heat Transfer, International*; Student ed.; Richard, D. Irwin: Homewood, IL, USA, 1992.
- Ministry of land, infrastructure and transport (MOLIT). *Regulations on Design Standards for Energy Saving of Building*; MOLIT: Sejong, Korea, 2014.
- Xu, Y.; Knudby, A.; Ho, H.C.; Shen, Y.; Liu, Y. Warming over the Tibetan Plateau in the last 55 years based on area-weighted average temperature. *Reg. Env. Chang.* **2017**, *17*, 2339–2347. [CrossRef]

-
24. Lee, H.W.; Diop, S.; Kim, Y.S. Variation of the overall heat transfer coefficient of plastic greenhouse covering material. *J. Bio-Env. Control.* **2011**, *20*, 72–77.
 25. Feuilleley, P.; Issanchou, G. Greenhouse covering materials measurement and modelling of thermal properties using the hot box method, and condensation effects. *J. Agric. Eng. Res.* **1996**, *65*, 129–142. [[CrossRef](#)]
 26. Japan Greenhouse Horticulture Association (JGHA). *Handbook of Protected Horticulture*, 5th ed.; JGHA: Tokyo, Japan, 2015.